NEKK01
Tutor: Susanna Thede
Lund University
School of Economics and Management

Economic Growth and Technology Diffusion

Emphasizing the Importance of Developing Country Firm – Knowledge for Growth and Income Convergence

Gustav Personne
840217-1477
Bachelors Thesis
Spring 2009
15 ECT

Abstract

In this paper I build upon the theory of endogenous economic growth to explain the presence or absence of convergence between the industrialized and the developing world. This is done by emphasizing the role of the business firm as an avenue to technological "catch up". I suggest that the importance of knowledge incorporated within the private business firm and it's effect on the process of technological assimilation and economic growth has been somewhat neglected in the earlier models of aggregated growth. By presenting a model of technology diffusion that builds upon the traditional models of endogenous growth, but includes the business firm as a hub in the process of technology diffusion, I show that it is insufficient to focus solely on human capital, as it is described in the growth literature, as being the main contributor to technology diffusion without explaining its more direct effects on the process of production and growth.

Keywords: R&D, Technology, Convergence, Diffusion, Economic Growth.

Table of contents

1 Introduction and Statement of Purpose

From the early economic theories derived from the thoughts of economists such as Adam Smith and Thomas Malthus, through the neoclassical growth theory represented by the Solow –Swan model up to the new theories of endogenous growth, many of the questions have been the same. Why do countries grow? Why do they grow at different rates, and, as is the focus of this paper, what is needed for the developing countries to "catch up" to the income levels of the industrialized world?

Why do some developing countries seem to converge to the levels of per capita income that are equivalent to the industrialized countries at a rather quick pace while others are lagging behind? How come that a country like Taiwan, which only 50 years ago exhibited all the trade marks of a developing economy, today is one of the most industrialized economies in the world (Gunnarsson and Rojas, 2004:120)? Korea is another example of a developing country exhibiting rapid growth and "has become one of the major producers of the communication devices and semiconductors, which mostly demand a high technological knowledge base" (Yang et al. 2006:605). As a result of this the knowledge base of Korea is gaining international competitiveness. (Yang et al. 2006:605)

In this paper I build upon the theory of endogenous growth to explain the presence or absence of convergence between the industrialized and the developing world. This is done by introducing the concept of firm - knowledge as an avenue to technological improvements and income convergence. Here, the knowledge of the individual worker is assumed to be absorbed by the business firm.

The behaviour of firms in accumulating technology can be said to be determined in part by market signals and in part by government policy. Within a policy environment, however, firms may differ in their responses to a complex present and an uncertain future, depending on for example the skills they have accumulated and the discretionary judgements their managers have made (Haque et al.1995: 91).

The purpose of this paper is not to investigate these differences in detail but to present a simple model of aggregated growth that produces credible results and provides intuition as to how a country makes the transition from being a technological follower to becoming a technological leader.

The main contribution of this paper is that it addresses the process of technological transfer and diffusion between the developed and the developing world from a new perspective using the accumulated knowledge of the business firm as the hub of technological diffusion that spurs the transition from imitation to innovation.

Drawing inspiration from the model of technological diffusion presented in ”Introduction to Economic Growth” by Charles I. Jones (Jones 2002:124 136) the objective is to broaden the theoretical view of what is needed for technology to move swiftly between countries of different technological level by including a new explanatory variable. Unlike the model presented by Jones, the model developed here succeeds in providing intuition of how developing countries can reduce their dependence upon technology produced abroad. The explanatory success of this paper lies partly in the expansion of the concept of research and development.

In the article "Technological Accumulation and Industrial Growth" Martin Bell and Keith Pavitt claim a model of technological diffusion “based simply on the adoption of new, more advanced types of machinery” (Bell and Pavitt, 1993:201) is inadequate. They claim that the description of technology as strictly embedded in physical capital does not captured the concept of technological transfer and diffusion in a satisfying way.

I stress here that the success of the transfer and diffusion of technology is dependent upon the specific knowledge held by the technology receiver. Even with the recognition of the differences in accumulated human capital between the developing and the developed world, the reasoning of Bell and Pavitt holds and this type model “fails to explain what is needed, not just to operate machines, but to choose them in the first place, improve upon their performance once acquired“ (Bell and Pavitt 1993:201). To explain how this type of knowledge is assimilated one has to go beyond the simple definition of human capital used in much of the growth literature to date, and explain how developing countries are able to close the gap to the technological leaders in a more credible way.

The simple neoclassical - style model of growth introduced below explains the differences in growth rates and a possible ”catch up” as depending on the abilities to adopt and assimilate new technology. As we have understood this has traditionally been done by pointing at the differences in accumulated human capital. In this paper, however I do it by introducing the concept of firm - knowledge. This model emphasises a conscious R&D effort by the business firms in the receiving country as a way to improve their ability to assimilate new technology and expand their technological knowledge.

The paper is divided into four sections where section one is a description of the earlier work that has been done on convergence, technological transfer and diffusion and puts the main contribution of this paper in relation to that. The second part defines the connections and differences between technology transfer and diffusion and discusses the accumulation of firm - knowledge through applied R&D. In the third part of the paper I present a simple but intuitive neoclassical - style model of growth that explains the differences in growth rates and a possible convergence as depending on the different abilities to assimilate new technology. This is done by drawing on the theoretical and empirical knowledge base and by incorporating the business firm as the hub in the process of technological transfer and diffusion. This is followed by a discussion of the results that can be retrieved from the model in section four.

2 Background

The question that has attracted possibly the most attention in the literature of economic growth is whether per capita income in different countries is converging or not. It was found that poorer countries, like Italy and Japan closed the gap to the richer countries like the United States in a span of about a hundred years, beginning in 1870 (Romer 1994:4). This discovery was met with two objections. For one, the convergence only seemed to take place during the years since the Second World War. Before that, the per capita income was diverging. Second, the data set that was used only included countries that had successfully industrialized at the end of the same period (Romer 1994:4). These findings came to affect the advancements in the theoretical school of economic growth.

2.1 Technology in Earlier Models

In the earlier neoclassical models or highly simplified models used in trade theory, technology was described as an exogenous factor and assumed to be freely available to all countries and within countries, to all firms. Countries where simply to settle on the appropriate level of capital/labour intensity as there were no problems in assimilating transferred technology (Lall 1992:165).

There were many indications that this was an unsatisfactory explanation. For example Martin Bell and Keith Pavitt noted that textile producers in Kenya in the 1980s, operated at lower levels of productivity than those in the industrialized countries in spite of the fact that they had access to similar spinning and weaving technologies. At the same time, textile producers in the Philippines, who were using the same types of equipment, were failing to reach even the productive levels of the Kenyan workers (Haque et al. 1995:70). Even though these examples seemed to indicate that there was something more to technology than its physical part, the assumptions regarding technology persisted in the growth literature.

As is described by Andrew Bernard and Charles Jones, technology in these models is reduced to being an indicator of the overall productivity in the economy. There are no lags on technological accumulation and all economies are "assumed to accumulate technology at the same rate" (Bernard and Jones, 1996:1037). Differences in growth rates are assumed to originate from differences in capital accumulation. The choices made, presumably by business firms, to adopt and accumulate new technology are left out of the discussion concerning both relative output levels, growth rates and convergence (Bernard and Jones, 1996:1037). The value of knowledge generated within the business firm is not considered in these models as technological effort is assumed to be irrelevant (Lall 1992:165).

The persistent differences in technology between countries have finally started to get the attention they deserve in the convergence debate as the failure of the cross-country convergence motivated the development of the "endogenous" growth models. Where the neo-classical models failed to explain the persistence in growth, these models explained technological change by dropping the two central assumptions of the neoclassical model: that technological change is exogenous and that the same technological opportunities are available in all countries of the world (Romer 1994:4).

In chapter six of his book "Introduction to economic growth", Charles I. Jones, presents a model of technological diffusion. Jones considers a small country far from the technological frontier. The model considered by Jones builds on the foundations of the model of endogenous growth presented in the paper ”Endogenous Technological Change” from 1990 by Paul Romer but adds to the model an ”avenue for technology transfer” (Jones 2002:124). The main contribution of Jones' model of technological diffusion is the role of human capital as the avenue of technological diffusion and income convergence. Technology is here considered to be a measurement of the number of intermediate capital goods used in production. The more capital goods the country is able to use, the higher is their technological level. Jones assumes that the number of capital goods that workers are able to use in production is limited by their skill level (Jones 2002:125). Jones also implicitly assumes that the country in question does not produce any technological knowledge at all. The growth rate of the economy is entirely depending on the ability of the workers to learn how to use technology produced elsewhere.

Jones's view of the importance of human capital, correct as it may be, becomes less relevant if one disregards the process through which human capital actually affects economic growth. How is the knowledge of the individual utilized in the process of production? In this process, the knowledge accumulated within the business firm is central.

Martin Bell and Keith Pavitt write that, "the assumption that developing countries can generate technological change simply by choosing and adopting technologies from industrial countries has often obscured the importance of accumulating relevant domestic assets" (Haque et al. 1995:72) and the model presented by Jones does not explain how, and if, the follower country breaks free from the technological dependence of the leading countries. According to Andrew Bernard and Charles I. Jones, the empirical convergence literature with regard to the importance of adoption and accumulation of technologies for income convergence has to date been largely misguided (Bernard and Jones, 1996:1037).

The model considered in this paper leaves the main assumptions of Jones' model intact but the focus is shifted form the knowledge of the individual (human capital), to the knowledge accumulated within the business firm. Even though individual knowledge lay at the heart of the business firm, there is a distinction between human capital at the individual level and firm - knowledge. To have an effect on production and growth, the knowledge of the individual needs to be taken up into the firm and moulded into a body of firm - knowledge. This is for example illustrated by the fact that many companies in Korea spent a lot of effort trying to diffuse international competitive knowledge into their organization because they wanted the knowledge to be "embodied not only into the workers but also within the company itself" (Yang et al. 2006:618).

Producing a model where growth is dependent on the accumulation of human capital through public education is simply not enough to describe the journey from imitator to innovator. In this type of model the follower country is constantly dependent on foreign technology as an input in production.

3 Technology Transfer and Technology Diffusion

How does technology transfer between countries? As the process of technology transfer and diffusion is central to this paper it is important to have a clear understanding of what these concepts represent. These two concepts are often used as substitutes for one another but I suggest that equating them may be partly misleading. I claim that technology can be transferred without being diffused but not diffused without being transferred. The process of technological diffusion is here determined by the channels of technology transfer and the technological capabilities in the follower country. The level of firm - knowledge accumulated within the receiving country makes up these capabilities.

There is a lot of work done regarding the effects of technology transfer, for example in the form of foreign direct investment (FDI). Although it is not the purpose of this paper to investigate the efficiency of the different channels of technological transfer, as the focus here is primarily on the technological ability of the receiving country, it is important to at least acknowledge their contribution

The process of technological transfer is for obvious reasons important to the follower country. It creates the possibility to access new technology in the first place. Hence it would be a mistake to ignore the channels of technology transfer altogether.

The technologically lagging countries tend to start by imitating new technology produced in the more advanced countries before making the shift to production of technological innovations. This type of behaviour can be found, for example in the newly industrialized countries of East and Southeast Asia that recently have shown strong indications of converging towards the levels of income and technology of the developed world (Hu et al. 2005:780).

There are many ways in which technology is transferred between countries and imitation may occur through different channels. Some of these that are mentioned by Albert Hu, include market – mediated purchases of technology, technology transfer from multinational corporations to local subsidiaries, joint ventures, FDI, or the reverse engineering of products and capital goods. The relative contribution of these channels to technological development has varied between countries (Hu et al. 2005:780).

One of the simplest ways of describing the process of technological transfer is that, in which technology is transferred from the technological leader to the follower embedded in physical capital goods. At the end of the Second World War the belief was that the technology accumulated in the industrialized world could easily be used to benefit the developing world in their pursuit for economic growth. One tended to overlook the fact that many of the technologies developed in the industrialized countries did not fit the needs of the less developed countries (Kim et al 2000:69). There are many types of knowledge that are not embedded in material inputs such as production patterns for example (Pack 1994:62). The definition of technological knowledge as something that can be distributed as a physical object or a written instruction is not very accurate. Many parts of what actually constitute successful technology transfer and diffusion are easily disregarded if the definition of technology becomes too narrow.

3.1 Domestic R&D and Technology Transfer

The relationship between domestic R&D and imported technology is one of much debate. The question is whether imported technology substitutes for, or complements domestically produced R&D.

By promoting domestic R&D as a substitute for technology transferred from industrialized countries, the developing country governments sometimes indicate that there might exist a "trade – off" between domestically sponsored R&D, and technology purchased "off the shelf" from technologically advanced countries (Hu et al. 2005:785). In contrast to this belief however, the main bulk of recent studies seem to show that domestic R&D and technology transfer are highly complementary and that ignoring the possibility of technological improvements through investments in foreign knowledge and technology may be considered doing the country a disservice (Pack et al 1997:86).

Keeping this in mind, the role of domestic R&D and foreign technology in boosting firm performance may be quite different. According to the research conducted by Albert Hu, Gary Jefferson and Qian Jinchang, foreign technology transfer generates measurable productivity gains when combined with R&D. This indicates that local R&D is important to get the best possible effect out of foreign technology transfer. Also, the addition of technology transfer raises the returns to in-firm R&D suggesting that the relationship works both ways (Hu et al. 2005:785).

Some economists such as Sanjaya Lall points at the dangers of acquiring mature technology. He stresses, for example, that FDI has the potential of being a very efficient channel through which technology can be transferred. It can provide beneficial by-products to local skill creation for example, by the contribution of additional competition to local firms. This in turn, is thought to create an environment that spur innovative activity. The problem is that the developing country that engages in FDI tends to lose out on the actual process of innovation. By simply receiving the results of the innovative process, there is no way they can assimilate the tacit knowledge needed to become successful in conducting their own R&D (Lall 1992:170). This in turn may prove disadvantageous for the country in the long run as it fails to accumulate the firm - knowledge needed to make the transition from technological follower to leader.

Instead it might create a situation of dependence on imports of new technology where the follower country is forced to pay ever-increasing amounts to get access to new and more advanced technology.

While the competitive aspects of FDI may indeed spur innovation, Howard Pack suggests that there are other channels of technology transfer that may be more advantageous for developing countries. For example the including aspects of joint ventures and technology licensing will typically result in a greater transfer of knowledge to domestic firms contributing to the accumulation of firm - knowledge in a more efficient way (Pack et al. 1997:88).

3.2 R&D, Innovation, Imitation and Diffusion

A lot has been written about the effects of R&D on innovation and imitation. These are ambiguous and often entangled concepts that may refer to different things depending on who you ask.

Among economists in general and in the growth literature in particular, the most common way to describe R&D is as an innovative process that generates one thing – new information (Cohen and Levinthal, 1989:569). This information, when used for a specific purpose, for example improvements in the process of production, is referred to as new technology. In a development framework, this process is thought to be exclusive to the industrialized countries and virtually obsolete in the developing world. The developing world is instead assumed to engage mainly in diffusion or imitation of already existing technology.

In the endogenous growth literature models with more than one sector of production have been developed. One sector might produce goods and services while another sector produces innovations in technology. Here firms are considered to produce goods and services used for consumption and capital accumulation while universities produce a factor of production called knowledge, which is then freely used in both sectors (Mankiw et al. 1995:298). Although this might be considered a useful simplification it comes with at least two inherent problems. Firstly it tends to ignore the contribution of the business firm in the process of innovation and secondly the definition of the concept of R&D and innovation may be too narrow.

The different definitions used to describe what actually constitutes an innovation are actually quite diverse. The process of technological diffusion might itself contain a considerable amount of innovative activity. The notion that technological transfer begins and ends with an investment in physical capital or the transfer of blueprints from one firm to the other can be largely misleading. Bell and Pavitt describe it as an ongoing, often gradual technical change, where the original innovations are moulded to fit the particular conditions under which they are to be operated. To be able to maintain competitiveness over time the technology often needs to be further improved once it's acquired (Bell and Pavitt 1993:160). The consequence is that it is almost impossible to decide where imitative or diffusional activity stops and innovation begins. What is important to recognize however, is that this process is taking place, foremost, at the firm - level.

Because of the difficulty in deciding what actually constitutes innovative activity it is also notoriously difficult to measure. Some scholars suggest that invention can be accomplished without research and that this type of innovative activity should receive the same type of attention as an important source of technical advances (Yang et al. 2006:604). Simple inventions are not likely to be protected by patents and are therefore hard to quantify. It can be of interest to keep these problems in mind when thinking about the value of the process of R&D and the "spill – over" effects that comes with it.

In contrast to the simplified models of endogenous growth, there is quite a lot of research suggesting that R&D is important, not only to the most technologically advanced countries but also in the developing part of the world and it does take place outside of the universities as well. The objectives and gains of conducting R&D however may differ substantially between the industrialized and the developing countries.

The model of technological diffusion presented in Jones' book shows the rate of convergence between the technological leader and the follower to be dependent on the accumulation of human capital in the follower country.

In the book "Economic growth" by Robert J. Barro and Xavier Sala I Martin they present a model of two countries, one technological leader and one follower. They assume that the follower country, which is assumed to be far from the technological frontier, has the option to imitate already existing technology at a lower cost than if they were to produce the same technology through invention (Barro and Sala I.Martin 1995:266). This has a negative effect on the incentives for R&D and innovative activities in the follower economy concluding that the follower will not conduct any innovative activity until the technology gap is small enough for it to be profitable. Bell and Pavitt suggest that since diffusion is often seen as a process of merely choosing, acquiring and adapting existing technologies embodied in capital goods, the need for developing countries to accumulate capabilities for innovation is often bypassed in the debate (Haque et al. 1995:74). This in turn risks becoming a lag on the process of technological transition of the developing country.

Even though Barro and Sala I Martin may be closer to the truth than Jones, these models both omit an important implication of the R&D process. The fact that there is no clear-cut distinction between the kinds of activities and resources required for innovation and those required for imitation (Haque et al. 1995:92) raises questions regarding the assumptions as to where R&D should be conducted.

This limitation was acknowledged by Wesley Cohen and Daniel Levinthal in the paper "Innovation and Learning, the two faces of R&D". Here they consider the possibility of a second effect of R&D. Besides the usual effort of creating new inventions there is also the effect of enhancing the firms' ability to assimilate and exploit existing knowledge (Cohen and Levinthal 1989:569). This second implication of R&D may well be of crucial importance when discussing technology transfer between the developed and the developing world using the knowledge of the business firm as the hub for technological transfer and assimilation. They suggest that, if the cost of imitation is relatively small, this depends on the fact that the firms in the vicinity of the area where the new technology first was produced, has already made considerable R&D efforts. The firm must already have invested in their absorptive capacity within the relevant field to be able to keep their adoptive costs down. They consequently draw the conclusion that the long run cost of learning or imitating might be quite substantial (Cohen and Levinthal, 1989:570). This conclusion also serves to highlight the importance of competence within firms when adopting new methods of production or technology.

This second effect of R&D sheds new light on the discussion of what R&D is, where it should be conducted and by whom. If it is the case, as John E. Tilton suggests, that R&D in fact contributes to keeping firms abreast of the latest semiconductor developments and facilitate the assimilation of new technology (Tilton 1971:71), then there should be incentives for firms everywhere to keep at least a basic R&D unit going to serve this purpose.

This theory is supported by evidence that the diffusion of new technology may take a considerable amount of time even between countries that are quite similar and share a lot of common features. An example of this, presented by Rachel Griffith in the paper “Mapping the Two Faces of R&D, Productivity Growth in a

Panel Of OECD Countries" taken from the allied countries during the second world war is the case of the jet engine: when plans were supplied by the British to the Americans during the second world war it took ten months for them to be redrawn to conform to American usage (Griffith et al. 2004:883)

Griffith points out that by actively engaging in R&D one can acquire the tacit knowledge needed to more easily understand and assimilate technologies produced elsewhere (Griffith et al. 2004:883). It can also be thought to help create a platform for a transition from imitator to innovator by building a technological knowledge base

3.3 Applied vs. General R&D

R&D can be privately or publicly funded. Even though both of these types of R&D generate new information and new knowledge, the objectives of their existence may be quite different, and so may the knowledge they produce.

Public R&D can, in very simple terms, be thought of as generating basic or general knowledge. In many cases the effect of public research on productivity is not measured. This is generally because the effect is indirect or because its results are not integrated in existing measures of GDP (Guallec et al. 2001:105). In the traditional way of considering applied R&D, or more specifically, R&D performed by business firms, it is assumed to result in new goods and services, in higher quality of output and in new, more effective, production processes. Applied R&D, conducted by business firms may be funded by the business itself or by government (Guallec et al. 2001:105).

In the model presented below we consider applied R&D conducted by firms in the developing world to have two main objectives: creating improved products out of already existing knowledge and improving the capacity to remodel existing products to fit the market in which the firm operates. That is, we assume that the firms in the developing economies initially do not participate consciously in R&D activities devoted to innovation of new ground - breaking discoveries.

In the industrialized world, this type of applied research can be assumed to be conducted mainly by private firms and primarily funded by the private business sector. However, in developing countries large commitments from the government may be necessary to overcome market failures that keep private business from investing in R&D. One explanation for this may be that restrictive trade policies may hinder firms from participating in the competitive world market and thereby produce a lack of incentives for private business to improve their productivity. This transfer to a limited demand for applied R&D. (Kim and Nelson, 2000:69)

3.4 The Hub of Technological Diffusion – The Importance of Firm - Knowledge

Without ignoring the relevance of national policies, infrastructure and many other factors when discussing technology diffusion, one cannot ignore the importance of the knowledge created within the business firms operating in the receiving country. These firms represent the ”locust of technological accumulation” (Dosi et al. 1994:25-26) and it is through them that the main part of the diffusion and assimilation of technology takes place. In the model presented below the knowledge of the firm is the determining factor in a country's ability to absorb new technology.

According to Martin Bell and Keith Pavitt, productivity in the receiving countries may differ even if the technology transferred is an established one that does not suffer from the uncertainty often associated with new, untested technology. They attribute these differences to differences in capabilities of technological management in the receiving country (Haque et al. 1995:85). Bell and Pavitt also stress another important part of the process of technological transfer. This is the part played by the receiving business firm. They suggest that “technologically dynamic firms rarely play a purely passive role during the acquisition of technology” (Haque et al. 1995:85). Because they participate in choosing and adapting the new technology, the success of the investment and the efficiency of the technological assimilation process can be said to depend on the amount of accumulated knowledge these firms possess.

There are alternatives to enhancement of technological capabilities for firms established in follower countries. According to Keun Lee and Chaisung Lim, the firms have the possibility to increase their market shares without enhancing their technological capabilities. This can instead be done by relying on imported technology combined with cheap local labour. They suggest that a sustained increase in market shares for these firms is very difficult to obtain if not accompanied by increases in technological capabilities. If these firms do not increase their technological capabilities, they will find it more and more difficult and expensive to buy the technologies needed for higher level market shares (Lee and Lim, 2001:461). If the appropriate platform of knowledge is not in place as the firm approaches the technological frontier, it may be unable to make the transition from follower to leader.

3.5 What is Firm - Knowledge?

It is important to provide intuition about how investments in human capital actually affect economic growth. By describing knowledge in the community as being accumulated solely by individuals through public education one tends to disregard important implications of the concept of knowledge.

Human capital as described by Jones is in many ways more concrete a concept than that of firm – knowledge. There are, however, differences also in the descriptions of human capital. Mankiw distinguishes between “knowledge” and “human capital” referring to knowledge as "society’s understanding about how the world works" and human capital as "the resources expended transmitting this understanding to the labour force" (Mankiw et al. 1995:298). In a way, this definition also makes it easier to understand why it is important for companies to develop knowledge that is embedded in the firm as opposed to knowledge specific to the individual. To use the language of Mankiw, the firm needs to develop it’s own understanding about how the world works.

In the article “Investment in Humans, Technological Diffusion and Economic growth" Richard Nelson and Edmund Phelps suggest that the rate of return to education grows with the technological progressiveness of the economy. They indicate that the progressiveness of technology has implications for the “optimal capital structure in the broad sense” (Nelson and Phelps, 1966:75), suggesting that investments in human capital becomes more important as the pace of technological “upgrades” quicken. (Nelson and Phelps, 1966:75). While this is a valid point, this type of reasoning again tends to separate the creation of human capital and the stock of technological knowledge.

Human capital is often measured by enrolment in educational systems and, sometimes, if one is lucky, the efficiency of education is taken into account by measurements of educational attainment (Barro and Lee, 1997). This type of measurement of human capital stems from the belief that the process of education can be viewed as an act of investment in people, and that educated people are bearers of human capital (Nelson and Phelps, 1966:75). A higher educational level of the population makes it possible for the country to use more advanced technology. In addition to this, most, if not, all economists recognize the importance of additional education, such as "on the job" training, as a part of the accumulation of human capital. Even so, the importance of the competence generated within the business firm is often left out of the more general growth models. By focusing on the knowledge created within the firm I am able to add a new perspective from which one can consider technological diffusion and assimilation.

Firm - knowledge is more than merely the aggregated knowledge of the individuals within the business firm. It has an effect, both on the productivity of the labour force and on the “quality” of capital investments. The description of investment capabilities used by Sanjaya Lall is in many aspects also applicable to the concept of firm – knowledge. It can be regarded as “the skills needed to identify, prepare and obtain technology to design, construct, equip, staff and commission a new facility”. These skills also determine the capital costs of the projects by improving the knowledge needed to make the “right” investments (Lall 1992:168). These skills are considered to be embedded within the firm.

R&D activity directed towards adapting and improving new types of technology is of crucial importance in the process of firm - knowledge accumulation. In the same way that Kim describes the concept of organizational learning, I consider the body of firm - knowledge to be acquired through a process of research and development that creates knowledge. This knowledge is then distributed throughout the business firm. It is, as Kim suggests, “communicable among members, has consensual validity, and is integrated into the strategy and management of the firm” (Kim, 1999:119). Without the assimilation of knowledge into the firm, the firm and, in the long run even the country, will continue to be dependent on external knowledge in choosing and adapting new technology in their production process.

The definition of firm - knowledge used in this paper follows, in part, the definition of ”absorptive capacity” used by Linsu Kim in the paper ”Building Technological Capability for Industrialization: Analytical Frameworks and Koreas Experience” (Kim, 1999:115). Here he refers to absorptive capacity as consisting of two elements: existing knowledge and the intensity of effort. In my definition of firm - knowledge I keep a strong focus on the effects of the R&D process as a foundation of creating technological understanding and ”know how” within the firm and ultimately within the country.

In the context of this paper, the developing country can be assumed to be heavily dependent on its abilities to make smart and effective investments in new and better types of technology as well as developing and adapting these to the particular conditions in which they are meant to operate. These abilities can only be improved through a continuous process of firm - knowledge accumulation.

4 The Model

The model presented below is a model of technological diffusion. We consider a small country that is separated from the technological frontier. It does not initially engage in innovative activity in the sense that its R&D effort is strictly devoted to applied research and focuses on the imitation and adaptation of already existing products.

The production function presented here is a simple Cobb – Douglas type of function. It is produced to explain the impact of firm – knowledge on the process of technology transfer from the advanced country in the developed world to the less advanced country in the developing world and its impact on economic growth.

$$Y = K^{\alpha}(FL)^{1-\alpha}$$

To increase the intuition of the model I make some simplifying assumptions. I assume that countries produce a homogenous output good Y, using, K - the stock of physical capital used in production and L - the amount of labour or the size of the economy. F is the stock of accumulated firm - knowledge within the country in question. F is a measure of productivity of the workforce but it also has an impact on the accumulation of capital through its share of investment. We assume a constant employment rate so the workforce grows at the same rate as the population. This growth rate is denoted by (n). α is the return to capital and takes on a value between zero and one[1].

The absolute changes in income say nothing about the effect on the standards of living of the people in a country. I am therefore more interested in the changes in income per capita.

[1] See appendix for explanation

I modify the model by dividing with the population L and end up with the expression:

$$y = k^{\alpha} F^{1-\alpha}$$

where:

$$y = \frac{Y}{L}$$

and:

$$k = \frac{K}{L}$$

4.1 Accumulation of Capital

The accumulation of capital per capita in the model follows much of the neoclassical model of capital accumulation presented by Jones, where capital per capita is assumed to accumulate because of investments in new capital less the depreciation (d) of the existing capital stock and the growth rate of the population (n) (Jones 2002:27).

We denote the accumulation of capital by a "dot" above the parameter k:

$$\overset{*}{k} = sy - (n + d)k \qquad (1)$$

sy is the total amount of investment, where s is the share of per capita income devoted to investment as opposed to consumption. In this model we separate the investment expression sy used in the original Solow model in to two distinct parts. $s_F y$ is assumed to represent investment in applied R&D that captures the intensity of effort in improving the level of firm – knowledge.

$s_K y$ represents the share of investment in the physical capital stock and basically picks up the rest of the share of investment but is referred to simply as the investment in capital.

$$s_K y + s_F y = sy$$

The separation of investment gives rise to questions regarding a possible trade - off between investing in applied R&D or in, for example physical capital. The complementarities of indigenous R&D and technology transfer discussed above suggest that both s_F and s_K are important for the technological development of a follower country. Investment in physical capital is needed to gain access to new forms of technology that can be imitated through for example reverse engineering, while the investments in applied R&D build the knowledge base within the firm for this type of activity. The acquisition of firm – knowledge increases the efficiency of capital investments by providing additional "know – how" regarding which investments that are best suited for the needs of the firm.

The model is solved by considering "state variables" that are constant along a "balanced growth path" (Jones 2002:56). In this case the state variable is defined as:

$$\tilde{y} = \tilde{k}^{\alpha} \qquad (2)$$

where:

$$\tilde{k} = \frac{K}{FL}$$

and:

$$\tilde{y} = \frac{Y}{FL}$$

Using the mathematical trick of taking logs and derivatives[2] gives us an expression for the growth rate in the state variable $\tilde{k}$

[2] See appendix for explanation

$$\overset{*}{\tilde{k}}/\tilde{k} = \overset{*}{K}/K - \overset{*}{F}/F - \overset{*}{L}/L$$

Rearranging and substituting this into the original function for capital accumulation yields:

$$\overset{*}{\tilde{k}} = s\tilde{y} - (n + g_F + d)\tilde{k} \qquad (3)$$

We now have an expression where the accumulation of the state variable denoted by $\tilde{k}$, that is positively dependent on the share of investment devoted to capital and negatively dependent on the growth rate of the population, the growth in firm - knowledge and the rate of depreciation of the existing capital stock.

4.2 The Accumulation of Firm - Knowledge

The equation describing the accumulation of firm - knowledge is dependent on four different parameters where β is the elasticity of the technology with respect to effort through investment and ρ is the elasticity of already accumulated firm – knowledge with respect to the total investments in firm – knowledge and the technological frontier. They both take on values between zero and one. The function is presented as follows:

$$\overset{*}{F} = \theta((s_F y)^{\beta} A^{1-\beta})^{\rho} F^{1-\rho} \qquad (4)$$

Firm - knowledge is acquired through the process of R&D and technological learning. As mentioned above I, in part, follow Linsu Kim, using his description of absorptive capacity. This includes two important elements: existing knowledge base and the intensity of effort. (Kim 1999:115) In the model presented here, these elements are represented by the existing level of firm – knowledge, (F) and the investments diverted towards applied R&D ($s_F y$). First, however, we need to consider the world in which the firm exists.

4.2.1 θ - The Return to Applied R&D

All business firms in a country are faced with a number of exogenously given variables to take into account when they conduct their daily business. These variables can be thought of as the economic framework in which the individual firm exist and operate. Using the language of Sanjaya Lall, this framework is said to be made up by the technological infrastructure that provides information, standards, basic scientific knowledge and various facilities, too large to be owned by private firms (Lall 1992:170). Taking on a value between zero and one, the return to applied R&D can be thought of as an index of this economic and technological framework.

4.2.2 ($s_F y$) Intensity of Effort

The intensity of effort refers to the amount of energy relinquished by business firms to solve problems. If business firms do not attempt to internalize new technological knowledge, the long term effects of a country wide increase in the technological level may be far below its potential (Kim 1999:115).

In the model presented here, this effort is represented by the share of investment devoted to the accumulation of firm - knowledge through applied R&D.

4.2.3 (A) World Technological Frontier

This is a measure of the cutting – edge level of technology. The technological level of the economy is usually thought of as the number of intermediate capital goods available in production. As the model describes a country, which initially do not take part in the activities that is associated with moving the technological frontier forward through innovation, it takes the growth rate of technology at the front as given and A enters the model exogenously.

4.2.4 (F) The Existing Stock of Firm Knowledge

This is the accumulated stock of firm - knowledge that is held within the country. We assume that the accumulated amount of knowledge today, has a definite impact on the creation of knowledge tomorrow. Existing knowledge improves the ability to assimilate knowledge and thereby providing an opportunity of increasing the amount of knowledge held in the future (Kim 1999:115).

4.3 The Growth Rate of Firm Knowledge

By dividing both sides by F we get the percentage growth or the growth rate of F:

$$\frac{\overset{*}{F}}{F} = \left(\frac{\theta((s_F y)^{\beta} A^{1-\beta}}{F}\right)^{\rho} \qquad (5)$$

This gives us some intuition of what affects the rate of growth in F. As we can see, the growth rate of F is partially determined by the distance to the world technological frontier denoted by A.

The farther an economy finds itself from the frontier, the faster the growth rate of F will be. The reason for this is the assumption that the closer the economy gets to the technological frontier, the more advanced is the technology and the more firm - knowledge is required to take the next technological step. Basically it reflects the assumption that it is more difficult to learn how to use more advanced technology. This is complemented by the assumption that the closer the economy gets to the technological frontier, the more reluctant the leading firms in the frontier countries becomes in giving up their technological knowledge (Lee and Lim 2001:474).

4.4 Steady State Analysis

The "steady state" is the long run equilibrium of the economy. An economy finds itself in "steady state" when all variables grow at the same rate and the proportions of inputs in the economy are constant over time. (Weil 2009:60)

The growth rate of $\tilde{k}$ can be described by the function:

$$\frac{\overset{*}{\tilde{k}}}{\tilde{k}} = s\frac{\tilde{y}}{\tilde{k}} - (n + g_F + d) \qquad (6)$$

As mentioned above one of the properties of the steady state is that all variables grow at the same constant rate. This tells us that for $\frac{\overset{*}{\tilde{k}}}{\tilde{k}}$ to be constant, $\frac{\tilde{y}}{\tilde{k}}$ must be constant. This means the growth rates of y, k and F are the same as the growth rate of the population in steady state. Using the notation g_x to denote the growth rate of some variable (x) along a balanced growth path we get:

$$g_y = g_k = g_F$$

Remembering equation number (2) we substitute $\tilde{y}$ for $\tilde{k}^{\alpha}$

$$\frac{\overset{*}{\tilde{k}}}{\tilde{k}} = s\,\frac{\tilde{k}^{\alpha}}{\tilde{k}} - (n + g_F + d) \qquad (7)$$

The accumulation of the state variable $\tilde{k}$ must be equal to zero in steady state as both K, F and L grows at the same rate.

That is:

$$\overset{*}{\tilde{k}} = 0$$

Which tells us that:

$$s\tilde{k}^{\alpha} - (n + g_F + d)\tilde{k} = 0$$

Solving for $\tilde{k}$ gives us:

$$\tilde{k} = (\frac{s}{n + g_F + d})^{\frac{1}{1-\alpha}} \qquad (8)$$

Substituting this expression into equation number (2) gives us the expression for the steady state value of output per worker and firm knowledge.

$$\tilde{y} = (\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} \qquad (9)$$

We can now solve for the steady state output per worker where the steady state level of output per worker is denoted by y_{ss} and the steady state level of firm knowledge is denoted by F_{ss}:

$$y_{ss} = (\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} * F_{ss} \qquad (10)$$

As shown above, Firm Knowledge accumulates according to:

$$\overset{*}{F} = \theta((s_F y)^{\beta} A^{1-\beta})^{\rho} F^{1-\rho}$$

The growth rate of firm - knowledge is given by the function:

$$\frac{\overset{*}{F}}{F} = (\frac{\theta((s_F y)^{\beta} A^{1-\beta}}{F})^{\rho} \qquad (11)$$

We see that for the growth rate of F to be constant, the ratio of A and F also must grow at a constant rate. Therefore we can draw the conclusion that in steady state the growth rate of F must be equal to the growth rate of A:

$$\frac{\overset{*}{F}}{F} = \frac{\overset{*}{A}}{A}$$

Since we already know that the growth rates of F, y, and k are the same we can conclude that, in steady state, all the variables will grow at the rate of the technology in the long run:

$$g_y = g_F = g_A = g_k = g$$

Solving for the steady state level of F:

$$\frac{\overset{*}{F}}{F} = g_F$$

$$g_F = \theta(\frac{(s_F y)^{\beta} A^{1-\beta}}{F})^{\rho}$$

$$(\frac{g_F}{\theta})^{1/\rho} = \frac{(s_F y)^{\beta} A^{1-\beta}}{F}$$

$$(\frac{g_F}{\theta})^{1/\rho} * F = (s_F y)^{\beta} A^{1-\beta}$$

$$F_{ss} = \frac{(s_F y)^{\beta} A^{1-\beta}}{(((g_F)/\theta)^{1/\rho}}$$

Inserting this expression into the steady state expression from equation number (10) we get a steady state expression that is defined as follows:

$$y = (\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} * (\frac{(s_F y)^{\beta} A^{1-\beta}}{(((g_F)/\theta)^{1/\rho}}) \qquad (12)$$

Solving for y:

$$y^{1-\beta} = (\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} * (\frac{(s_F)^{\beta} A^{1-\beta}}{(((g_F)/\theta)^{1/\rho}})$$

$$y^{1-\beta} = (\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} * (\frac{g_F}{\theta})^{-(1/\rho)} (s_F)^{\beta} A^{1-\beta}$$

$$y = ((\frac{s}{n + g_F + d})^{\frac{\alpha}{1-\alpha}} * (\frac{\theta}{g_F})^{1/\rho} (s_F)^{\beta})^{1/(1-\beta)} A$$

Our steady state expression is hence:

$$y_{ss} = ((\frac{s}{n + g + d})^{\frac{\alpha}{1-\alpha}} * (\frac{\theta}{g})^{1/\rho} (s_F)^{\beta})^{1/(1-\beta)} A \qquad (13)$$

We can see from this expression that the steady state quantity of output per worker of the economy is determined by the investments in capital and the share of investment that is used to produce firm - knowledge through applied R&D, this as well as the front level of technology.

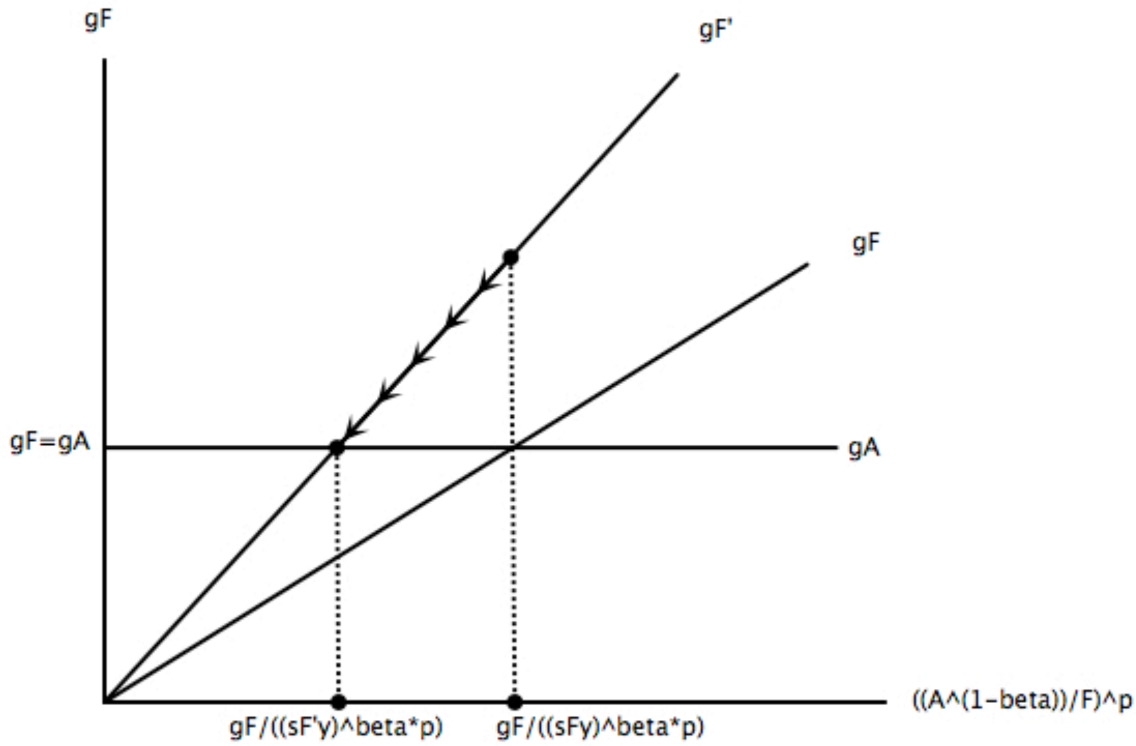
The growth rate of the technology however, has a negative impact on the level of output. This can be explained by the fact that an increase in the growth rate of technology in the frontier countries means that a country that is distinct from the technological front has to invest a larger amount in both capital and applied research to keep up with the technological leaders. They also have to take action to improve the return to firm level R&D not to lag behind. Technology enters the function because an increase in the level of technology in the frontier countries increases the long run level of output for all countries in this model.

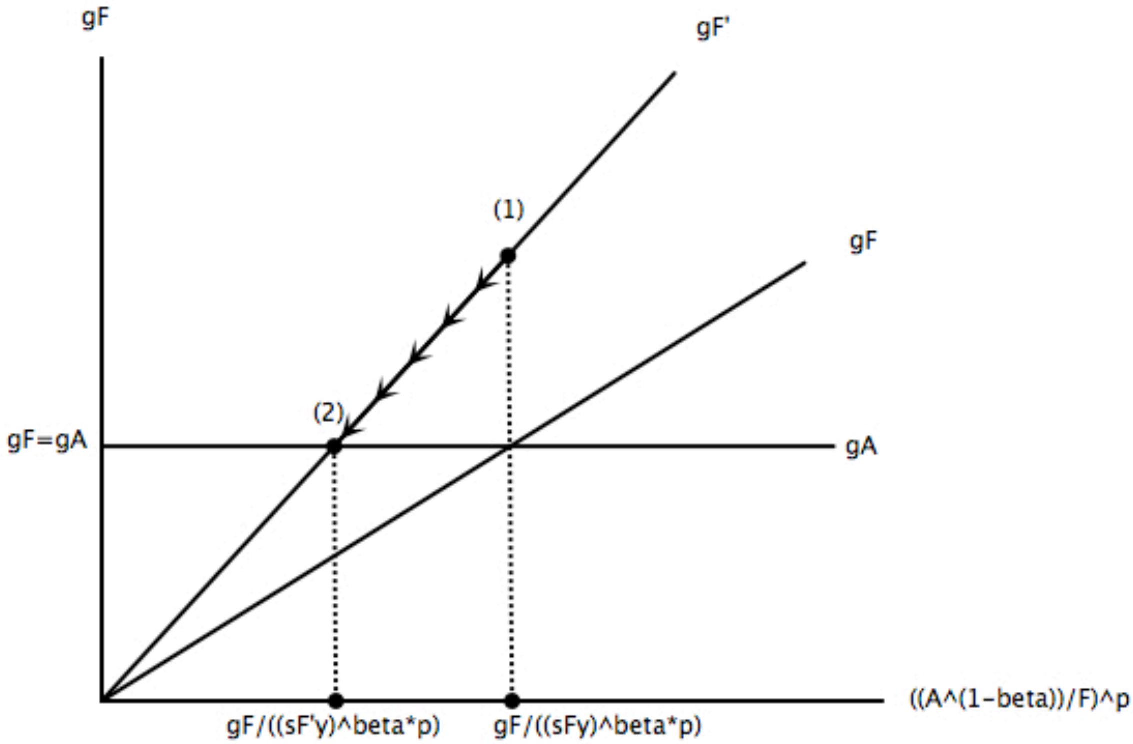
The model exhibits conditional convergence between the developed and developing world. That is, countries will converge to their own particular steady states (Mankiw et al. 1995:284) that are determined by their share of investment in applied research, investment in capital, economic structure and the growth rate of the population.

We can see that investments in firm – knowledge also have an effect on the physical capital as we remember that $s = s_K + s_F$. This can be interpreted as follows: investments in firm – knowledge raises the efficiency of investments in capital by raising the probability of making the "right" investments in new capital goods.

The model explains the differences in output as dependent on the differences in the adoption and assimilation of technology. The difference in the rate of convergence is explained by considering the different levels of capital and firm - knowledge accumulated by different countries.

It is obvious that the country in question has the ability to boost the growth

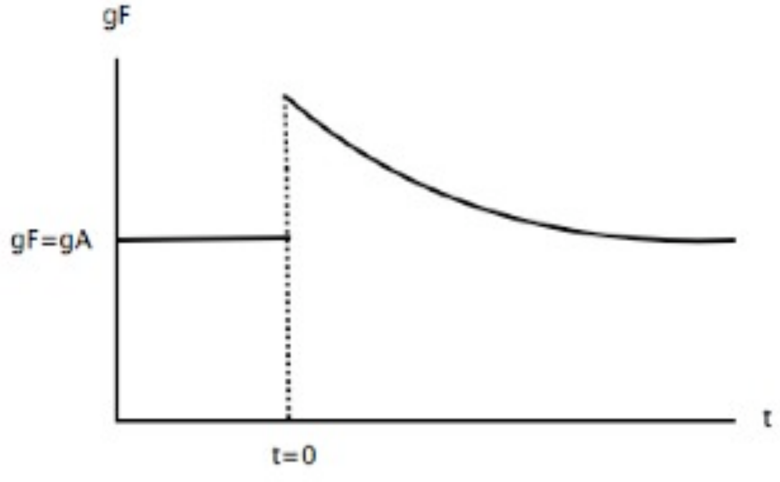




We assume that technology is growing at the constant exogenous rate g_A. For simplicity we assume the extreme and somewhat unlikely case where θ takes the value of one and β takes on a value close to zero. We also assume that ρ takes on a value close to one suggesting that the economy finds itself in a situation where the quality if the economic structure is perfect and the return to imported technology is large. We can see that if, for example, $s_F y$ increases by an arbitrary amount to $s_F' y$ producing an upward shift in $g_F = (\frac{\theta((s_F y)^{\beta} A^{1-\beta}}{F})^{\rho})$ to $g_F' = (\frac{\theta((s_F' y)^{\beta} A^{1-\beta}}{F})^{\rho}$ and the growth rate of F becomes faster than that of A (point 1 in the figure above) the ratio between the technology A, and firm - knowledge F will fall. This in turn drives the growth rate of F down until it is equal to the growth rate of A again (point 2). Now the ratio of A/F has fallen and the economy has made an effort of closing the output gap to the industrialized countries. However, the long run growth rate in the economy is not affected by the increase in investments diverted to applied research as it is tied down by the growth rate of technology.

4.4.2 Figure 2 (Change in the Growth Rate of F Over Time)

(2)



From this figure we can see the result of an arbitrary increase of the investments in applied R&D to $s_F'y$ at time t = 0. It will produce a temporary increase in the growth rate of F and then a gradual return to the growth rate of technology over time.

5 Discussion of the Model

What can this model tell us about the underlying mechanisms of successful technological diffusion? The model suggests that government policies that serves to create incentives for applied R&D within the individual firm are of great importance as, random firm-level differences apart, enterprises in any economy react to a common set of incentives when investing in technological effort (Lall 1998:215).

The economic framework (denoted by θ) in which all firms participate, is influenced by policy decisions and can be represented by what is sometimes referred to as ”the social infrastructure” (Jones 2002:136). There are different indicators of the ”quality” of the social infrastructure within a country and two important examples are the quality of the rule of law, especially in the form of the protection of ”intellectual property rights” and openness towards the rest of the world, represented for example by restrictions on trade.

IP protection is thought to have a profound effect on the return to applied R&D. Without sufficient IP- protection, the return to R&D will probably be low as the firms are unable to reap the benefits of their initial investment. This will in turn have a negative effect on the incentives of performing R&D. If the country in question is hampered by restrictive trade policies it might reduce its access to new forms of technology.

One cannot deny the prominent role of government in the technology acquisition of the Asian NICs[3] (Pack and Saggi 1997:84). For example, using an active development policy including protection against imports and selective exclusion of foreign investment, South Korea has managed to develop its technological knowledge base further than any other developing country in the world (Lall 1992:180).

[3] Newly Industrialized Countries

Sanjaya Lall describes the strategy as one of "protecting domestic technological learning" (Lall 1992:180) and means that South Korea demonstrates that protection of the learning process can be highly effective when complex large scale fast moving technologies are involved (Lall 1992:180).

As is widely recognized, this sort of government controlled growth strategy is far from successful everywhere and import substitution policies may have severe impacts on the technological development of countries that deliberately turn away from free trade and openness towards the rest of the world. The incentives to upgrade the process of production of firms operating within these countries are low as a result of the low profitability of export and their ability to compete in world markets suffers as an effect of this (Pack and Saggi, 1997:84).

Without sufficient access to international markets the acquisition of new technology will be difficult.

5.1 Intensity of Effort

Joon – Mo Yang describes the development of the newly industrialized countries (NICs) in East Asia as one where the R&D institutes has realized the importance of the second role of R&D described above. Instead of just emphasizing the development of new technological innovations, the focus is also on the role of R&D as a way of facilitating the integration of external technological knowledge into the local science community and the domestic business firms. As a result of this, the technological efforts of East Asia has tended to differ from the technological activities emphasized in other countries (Bell and Pavitt 1993:191).

In Korea the government played an active role in creating an efficient technological environment for the business firms. By only giving business permits to firms that actively sought to increase their technological knowledge through, for example, R&D alliances with car makers in industrialized countries they promoted the creation of technological knowledge within the firms and managed to accelerate the technological development of companies such as Hyundai, which in the early 1990s hired researchers as 10% of its total labour force (Yang et al. 2006:617).

Another example of the importance of this second role of R&D in the development of the East Asian NICs, is the Electronic Research and Service Organization of the Industrial Technology Research institute in Taiwan. The main objective of this institute was not to promote frontier technology innovations but to serve as a “focal point for acquiring existing foreign technology, assimilating it, training people to use it, and then diffusing both the technology and trained operators to firms” (Haque 1995:99).

This shows that R&D efforts have a significant purpose even if the main objective is not innovation in the way we may be used to think about it.

Because of a possible complementary relationship between general and applied R&D, the amount of general R&D performed by the individual country may also be of interest in determining the return to applied R&D. Besides generating a general knowledge base within the community, public R&D is often considered to have effects also on the productivity of private or applied R&D. The conductors of applied R&D can draw on the general knowledge created, to produce new technological innovations later to be used in production (David et al. 2000:499).

With this said it is, according to Sanyaja Lall, generally safe to assume that R&D financed and conducted by private enterprises is more effective than publicly financed and conducted R&D when it comes to producing results that are immediately valuable in production (Lall 1992:178). Even though the Korean government had a prominent role in the economic development of the country, some scholars still suggest that the private sector should get most of the credit for the technological advancements (Yang et al. 2006:618). While Hyundai surely benefited form the aggressive government policies, the large R&D effort made by the company, with the objective to gain the technological knowledge needed to be able to produce its own engines, can largely be attributed to the decisions made within the firm. The fact that Hyundai, today, produce 90 percent of the parts used in production locally is an effect of decisiveness and persistence by the management of the firm (Lee and Lim 2001:470).

5.2 From Follower to Leader - The Phase of Transition

As the country or firm makes technological advancement the ratio of technology to firm - knowledge (A/F) is decreasing. This means that the importance of applied R&D increases as the country makes the transition from imitation to innovation. If the R&D effort is not in place and the country has made itself too dependent on external technological knowledge by for instance relying too heavily on FDI, the transition may be slow or even absent and the firms, industries and eventually the country, will suffer.

In Korea, one effect of this can be seen in the industry of consumer electronic where the firms are having difficulty securing continuous access to the external knowledge base while their own R&D capability has not yet reached levels that allow them to stand on their own (Lee and Lim 2001:476).

In a survey that aims to investigate the technology environment in South Africa by a model of technology transfer through FDI in the electronics sector, Mzenda and Buys find that technology transfer is hampered by four major issues: rapidly declining R&D knowledge generating activity, the lack of locally innovative small and medium enterprises in the sector, unattractive and low government incentives and low inflow of electronics sector FDI. They conclude that a number of activities which are identified as means and channels through which technology can be transferred and diffused, such as training of technical staff, local R&D and local manufacturing, are taking place at low intensities (Mzenda and Buys 2006:1834-1835).

To be able to make the final leap from imitator to innovator we have seen that a country is dependent on an existing platform of technological knowledge. Looking beyond the electronics industry the business firms of Korea are some of the few that, in an effective way, has been able to build on the technological knowledge created by a conscious R&D effort and successfully manage the final step towards becoming technological innovators. They have shown that, with sufficient knowledge created through applied R&D and with large efforts in improving the technological knowledge base, imitative activity and R&D is quite easily transformed into innovative effort as they approach the technological frontier (Kim 1997:13)

Concluding Remarks

In this paper, I suggest that the role of the private business firm in the process of technological assimilation and economic growth has been somewhat neglected in the earlier models of aggregated growth.

By presenting a model of technology diffusion that builds upon the traditional models of endogenous growth but includes the knowledge of the business firm as the avenue of technology diffusion I have managed to show that there is reason to believe that it is insufficient to focus solely on human capital, as it is described in the growth literature, as the main contributor to technology diffusion without explaining its effect on the process of production and growth more thoroughly. The purpose here has been to highlight the importance of the business firm as a central actor in the transfer and diffusion of technology.

Growth in countries far from the technological frontier is shown to be dependent on the accumulation of firm - knowledge. The closer a country gets to the technological frontier; the more important is the intensity of effort within the firm to accumulate technological "know how". This is described as an effect of the decreasing will of competing firms abroad to share their technological knowledge together with the assumption that it is more difficult to learn to use more advanced technology.

Even though a lot of work has been done regarding the role of the firm in the process of technological diffusion the connection to economic development and growth, especially in the developing world has not always been satisfactory. This paper serves to clarify the role of the firm in connection to the discussion of technology diffusion, convergence, growth and economic development.

6 Appendix

6.1 “Alpha”

In a competitive economy the marginal product of capital will equal the rental rate per unit of capital – in other words, the amount firms are willing to pay to use a unit of capital. The derivation of the share paid to capital is taken form the book “Economic Growth” by David N. Weil.

The total amount paid out to capital will equal the rental rate per unit of capital multiplied by the total quantity of capital, that is, MPK*K. Capital’s share of income is the fraction of national income (Y) that is paid out as rent on capital (Weil 2009:56). Mathematically, the capital share is given by this expression:

$$MPK = \alpha K^{\alpha-1} L^{1-\alpha}$$

Capitals share of income:

$$\frac{MPK * K}{Y} = \frac{\alpha K^{\alpha} L^{1-\alpha}}{K^{\alpha} L^{1-\alpha}} = \alpha$$

6.2 "Taking Logs and Derivatives"

The properties of the natural logarithm are useful in the mathematical models of economic growth.

$$\tilde{k} = \frac{K}{FL}$$

Take logs of both sides:

$$\ln \tilde{k} = \ln K - (\ln(F) + \ln(L))$$

By taking derivatives to both sides with respect to time, we can see how the growth rate of output is related to the growth rate of the inputs in this example:

$$\frac{\partial \ln(\tilde{k})}{\partial t} = \alpha \frac{\partial \ln(K)}{\partial t} - \frac{\partial \ln(F)}{\partial t} - \frac{\partial \ln(L)}{\partial t}$$

Which is exactly the same as:

$$\frac{\overset{*}{\tilde{k}}}{\tilde{k}} = \frac{\overset{*}{K}}{K} - \frac{\overset{*}{F}}{F} - \frac{\overset{*}{L}}{L}$$

This last equation says that the growth rate of the state variable $\tilde{k}$ is equal to the growth rate of capital less the growth rate of firm – knowledge and the labour force.

7 References

Barro, Robert, J. and Sala I.Martin, Xavier 1995. *Economic Growth*, United States of America: McGraw – Hill Inc.

Barro, Robert J. - Lee, J. W (1997) "International data on schooling years and schooling quality", *American Economic Review, Papers and Proceedings* 86(2) 218-223

Bell, Martin - Pavitt, Keith, 1993. "Technological accumulation and industrial Growth: Contrasts Between Developed and Developing Countries", *Industrial and corporate change* Vol: 2 No: 2, Oxford University Press

Bernard, Andrew B. - Jones, Charles I. 1996. "Technology and convergence", *The economic journal* Vol 106 No. 437, pp 1037 – 1044. Published by Blackwell Publishing for the Royal Economic Society

Cohen, Wesely M. and Levinthal, Daniel A. Sep., 1989. "Innovation and Learning: The Two Faces of R&D" *The Economic Journal*, Vol. 99 No. 397 pp. 569 – 596, Published by Blackwell Publishing for the Royal Economic Society

David, Paul A., Hall, Bronwyn H. And Tool, Andrew A., 2000 "Is public R&D a complement or substitute for Private R&D? A review of the econometric evidence", *Research Policy*, No. 29 pp. 497 – 529. Elsevier Science

Dosi, Giovanni - Freeman, Christopher - Fabiani, Silvia, 1994. "The process of Economic Development: Introducing Some Stylized Facts and Theories on Technologies, Firms and Institutions", *Industrial and Corporate Change* Vol. 3 No. 1, Oxford University Press

Griffith, Rachel - Redding, Stephen - Van Reenen, John, November 2004. "Mapping the Two Faces of R&D, Productivity Growth in a Panel Of OECD Countries", *The Review of Economics and Statistics* 86(4): 883 – 895, The President and Fellows of Harvard College and the Massachusetts Institute of Technology

Guallec, Dominique - Pottelsberghe de la Potterie, Bruno van, 2001. ”R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries“, *Economic Studies,* No.33, OECD.

Gunnarsson, Christer – Rojas, Mauricio, 2004. *Tillväxt Stagnation Kaos, En institutionell studie av underutvecklingens orsaker och utvecklingens möjligheter,* second edition, Stockholm: SNS Förlag

Haque, Irfan ul – Bell, Martin - Dahlman, Carl - Lall, Sanjaya – Pavitt, Keith, 1995. “Trade, Technology and International Competitiveness”, International bank of reconstruction and development/THE WORLD BANK

Hu, G. Z. Albert - Jefferson, H. Gary - Jinchang, Qian, November 2005. “R&D and Technology Transfer: Firm – Level Evidence From Chinese Industry”, *The Review of Economics and Statistics*, 87(4) pp. 780 – 786.President and Fellows of Harvard Collage and the Massachusetts Institute of Technology

Jones, Charles I. 2002. *Introduction to Economic Growth*, second edition, United States of America: W.W. Norton & Company inc.

Kim, Linsu, (1 April) 1997. *Imitation to Innovation, The Dynamics of Koreas' Technological Learning,* United States of America: Harvard Business School Press

Kim, Linsu, 1999. “Building Technological Capability for Industrialization: Analytical Frameworks and Korea's Experience”, *Industrial and Corporate Change* Vol. 8, No. 1, UK: Oxford University Press.

Kim, Linsu - Richard Nelson, 2000. *Technology Learning and Innovation*, Edinburgh Cambridge University Press.

Lall, Sanjaya, 1992. “Technological capabilities and Industrialization”, *World Development*, Vol. 20, No. 2, pp. 165 – 186, Printed in Great Brittan, Institute of economics and statistics, Oxford, Pergamon Press.

Lall, Sanjaya, 1998. “Technological Capabilities in Emerging Asia”, *Oxford Development Studies*, Vol. 26, No. 2, International Development Centre, Oxford.

Lee, Keun – Lim, Chaisung, Lim, 2001. “Technological regimes, catching – up and leapfrogging: findings from the Korean industries” Research Policy No. 30, pp. 459 – 483, Elsevier Science.

Mankiw, Gregory N. - Romer, Paul M. - Phelps, Edmund S., 1995. "The Growth of Nations", *Brookings papers on economic activity* No. 1, pp. 275 – 326 Published by the Brookings institution

Mzenda, V.M. - Buys, A.J. 2006. "The Ambivalence of Technology Transfer through Foreign Direct Investments" PICMET 2006 Proceedings 9-13 July, Istanbul Turkey, pp. 1827-1835. PICMET University

Nelson, Richard R. - Phelps, Edmund S. (Mar. 1) 1966. "Investment in Humans, Technological Diffusion, and Economic Growth", *The American Economic Review*, Vol. 56, No. 1/2, pp. 69-75, Published by: American Economic Association

Pack, Howard, 1994. "Endogenous growth theory intellectual appeal and empirical shortcomings", *Journal of economic perspectives,* vol. 8 No 1 pp 55-72. Published by: American Economic Association

Pack, Howard - Saggi, Kamal, 1997. "Inflows of foreign technology and indigenous technological development", *Review of development economics* 1 (1), 81 – 98. Blackwell Publishers, Oxford, UK

Romer, Paul M., (Oct., 1990), "Endogenous Technological Change", The Journal of Political Economy Vol. 98, No. 5, Part 2: *The Problem of Development: A Conference of the Institute for the Study of Free enterprise Systems* pp. S71 – S102, Published by: The of Chicago Press

Romer Paul, 1994. "The origins of endogenous growth", *Journal of economic perspectives*, volume 8, No. 1, pp. 3-22. Published by: American Economic Association

Tilton, John E. 1971. *International Diffusion of Technology: The Case of Semiconductors*, The Brookings Institution, Washington

Weil, David N., 2009. *Economic Growth*, second edition, Boston: Pearson Education Inc.

Yang, Joon – Mo, Kim, Tae-Wan - Han, Hyun-Ok, 2006. "Understanding the economic development of Korea, form an co-evolutionary perspective", *Journal of Asian Economics* No. 17, pp. 601 – 621. Elsevier inc.